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SPECIAL SESSION ABSTRACTS

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PREFACE

In 1981, the Planetary and Earth Sciences Division (PESD) staff at JSC began thinking about future lunar scientific initiatives as part of a general reexamination of research goals and programs in planetary science. Soon thereafter, the new leadership in NASA took hold; and it appeared that the agency's future would emphasize even more strongly the development of the Space Transportation System (STS), possibly at the expense of some science programs. As we studied the implications of "man's expansion into near-Earth space", we realized that the future STS, with a capability to service geosynchronous orbit routinely, could reach lunar orbit equally routinely. Thus, the term "near-Earth space" potentially encompasses the Moon.

We quickly saw that utilization of the Moon could be the theme for a strong, synergistic interaction between the STS and NASA's space science programs in the context of future national needs and goals. It was only a few days after our first in-house briefing for programmatic support that we stumbled across the proposal from the Los Alamos National Laboratory entitled "An International Research Laboratory on the Moon: A Proposal for a National Commitment". The parallelism between the LANL arguments and ours was striking, almost eerie. That was the first of our many encounters with groups and individuals, mostly outside the space program, who see a manned lunar base to be important as the generator of a bow wave in the nation's science, technology, and innovation.

The abstracts in this volume reflect the variety of perspectives from which the lunar option can be viewed. The diversity of authorship is startling: planetary scientist, aerospace engineer, political scientist, high energy physicist, geochemist, policy analyst, administrator, geologist, educator, psychologist, military officer, futurist, etc. Had this forum not been so hastily arranged and poorly publicized, the spectrum of interest and the degree of enthusiasm would have been even greater.

However, interest and enthusiasm alone will not place the next human on the surface of the Moon. In our file cabinets languish past NASA studies of a lunar base and past administrative pronouncements on manned flights to the planets. The real question is whether the papers herein represent new growth or whether they are just more dying leaves, lifted in a passing breeze. We cannot know for sure, but perhaps there is a difference this time.

In 1983, space activities are part of the nation's business and become more so with each passing month. Very little vision is required to see the Space Transportation System reaching to the Moon. Development of the lunar option requires decisions today - but not dramatic ones. The decision process can be influenced significantly by an atmosphere of conviction, or skepticism, in the science and engineering community. In that context, the 14th Lunar and Planetary Science Conference is the kind of forum where a course for the future is set. What heading do you choose?

Wendell Mendell — Michael B. Duke

Wendell W. Mendell — Michael B. Duke

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IN SITU SOLAR FURNACE PRODUCTION OF OXYGEN, METALS AND CERAMICS FROM LUNAR MATERIALS.

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King (1,2,3) has shown that solar furnace melting and partial evaporation of samples of the Murchison and Allende meteorites as well as Columbia Plateau basalts, broadly comparable to lunar basalts, have produced residues enriched in elemental iron and silicon as well as the oxides of refractory elements like calcium, aluminum and titanium. Evaporation condensates of the above solar furnace process are enriched in iron-magnesium silicates and oxides of the more volatile elements like manganese, vanadium and sodium.

The experiments are conducted using a two meter parabolic mirror in a vertical access furnace that permits samples to be heated through a bell jar to temperatures of approximately 3000^{o}C in a crucible water cooled to a few hundred degrees Celsius or less. These features of the system preclude exchange reactions between the sample and the containment vessel. Furnace atmospheres include the ambient, hydrogen at light positive pressures, and dynamic vacuum ranging from mid 10^{-6} to one torr. Run times vary from minutes to hours.

Elemental iron and silicon have been produced from basaltic and meteoritic samples processed in both vacuum and hydrogen ambients. Substantial quantities of gas are generated by heating rock samples rapidly to high temperatures but, for sample weights of a few grams or less, pumping capacity has been adequate to keep vacuum runs below one torr during processing. Effluent gases have not been analyzed, but the appearance of metals and semi-metals in the residue strongly implies that oxygen and light oxides like H_2O, CO, CO_2, SiO and SO_2 are evolved. Over extended run periods, substantial quantities of liberated iron vaporize as well and probably recombine, at least in part, with effluent oxygen. However, short run periods and/or rapid cooling of effluents may significantly limit iron-oxygen recombination.

In the space environment, there is good evidence that reduction of iron from basalts has occured naturally during the formation of the stony-iron mesosiderite meteorites at igneous temperatures and lunar oxygen fugacities (4,5). Related reactions have been employed for many years in the steel industry to deoxidize iron at refining temperatures in excess of 1600^{o}C both at atmospheric pressure and at vacuum levels of 0.1 to one torr (6). Accordingly, solar furnace fractionation of lunar soils and basalts may be a potentially valuable process for iron and oxygen production on the moon if significant amounts of elemental oxygen and the light oxides can be separated and collected. For example, at least partial separation of high temperature effluents, including iron vapor, might be accomplished by rapid quenching of generated volatiles in condensers at lunar subsurface temperatures while oxygen and and other low temperature gases are adsorbed onto purified lunar soil fines in separate vessels.

In addition to the volatile and metal fractions of the solar furnace process, refractory residues of lunar materials may also be of considerable value on the moon. King found (1) that portions of the residues of basalts heated to approximately 3000°C in vacuum for 30 minutes contained only oxygen, calcium and aluminum as major elements. Apart from ceramic applications, the aluminum enrichment of these residues suggests they may be suitable as starting materials for aluminum extraction processes. In addition, titanium, chromium, scandium and zirconium are of particular interest in lunar basalts because they are already concentrated to substantially higher levels than in terrestrial basalts. Residues of solar furnace processed lunar materials might contain concentrations of these elements that are economic for lunar and cislunar applications. Terrestrial solar furnace processing research using appropriate lunar basalt and/or soil samples or their simulants would be productive in investigating the phases and concentrations of these and other useful elements that might be attained in a lunar solar furnace facility.

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LUNAR BASE REQUIREMENTS. Joseph A. Angelo, Florida Institute of Technology, Melbourne, FL, and David Buden, Los Alamos National Laboratory, Los Alamos, NM.

When man returns to the Moon, it will not be for a brief moment of scientific inquiry as occurred in the Apollo program, but rather as a permanent inhabitant--exploiting the lunar resource base in support of man's extraterrestrial civilization. A decision to exploit the space frontier gives humanity an infinite physical and psychological frontier in which to continue development and growth. The off-planet expansion of the human resource base will be marked by several major technology steps:

1. the development of reusable space transportation systems, such as the Space Shuttle;
2. the establishment of permanently inhabited space stations;
3. the creation of space-based industries;
4. the establishment of lunar bases and settlements;
5. the full exploitation of cislunar space and the lunar resource base. The Moon is man's gateway to all heliocentric space--and nuclear energy, reliable, abundant and portable, is the key to lunar development.

Future lunar settlements may at first be semi-permanent, and then grow to permanent occupancy. A 12-person lunar base would require 20-1000 kW of continuous electric power. As this base expands to a settlement of some 200 persons, these power requirements have been estimated to increase to the megawatt range. An advanced lunar settlement would require several hundreds of megawatts of power--especially if full exploitation and processing of lunar materials is to be achieved.

A typical space nuclear power plant consists of a nuclear reactor which serves as the thermal energy source, a radiation attenuation shield to protect individuals and radiation-sensitive equipment, power conversion equipment, and a waste heat rejection system. This paper provides an approximate ordering of leading nuclear technology candidates based upon reactor type, energy conversion system, and heat rejection system. Heat pipe reactor technology is currently under development in the SP-100 program at the Los Alamos National Laboratory. This program is aimed at developing a 10 to 100 kW_e, 7-year lifetime space nuclear power plant. Lithium heat pipes are used to transport thermal energy from the reactor core to thermoelectric converters. Because of their relatively low efficiency (i.e., < 10%) thermoelectric converters would be limited to nuclear power applications demanding less than 200 kW_e. From 200 kW_e to the megawatt-electrical level, there is a choice of dynamic conversion options (Rankine, Brayton or Stirling cycle) as well as possibly thermionic conversion techniques--all using the same basic SP-100 reactor design. As the demand for lunar power reaches the tens-of-megawatt levels, other nuclear reactor designs must be considered. These designs include solid core, fluidized bed, and gaseous core.

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LUNAR SCIENCES AND RESOURCES

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The possibilities for lunar science did not terminate with the end of the Apollo and Soviet lunar programs. It is obvious that many major problems have been intelligently and exhaustively framed by continuing lunar sample research and data analysis in the post-Apollo period but not solved. The origin of the moon or detailed understanding of its geological evolution are examples of problems that could be advanced immensely by a return to the moon. Two efforts could be started immediately which would lead to expanded lunar research on several fronts and introduce the use of lunar resources into the engineering planning of future space programs (1).

Comprehensive planning has been pursued since the early 1970's for lunar polar orbiting satellites which could immediately extend detailed knowledge of the moon to the entire lunar surface (2). It seems likely that major new lunar resources might be located, including large quantities of water-ice (3). We anticipate many general similarities between the moon and approachable asteroids. Systems developed and deployed to survey the moon can in large measure be applicable to reconnoitering earth approaching asteroids. Ground truth verification of lunar observations by polar orbiting satellites would significantly enhance confidence in the quality of asteroid observations by the same or similar systems.

The present lunar research program should be extended to encompass the development of lunar materials for use in support of permanent manned presence in space. This research and development would enhance the value of lunar knowledge. Materials scientists would bring new priorities to the study of analog and real lunar samples (4). Judging the value of particular lunar resources will require detailed interactive evaluations of both the engineering possibilities for economically using the resources as well as knowledge of the resources themselves (5,6). Several communities must be brought together which have not interacted deeply for some time if ever. The communities include the lunar sample investigators, NASA advance planners, experts on industrial materials and processing and researchers developing robotics and advanced manufacturing.

It is possible that the space transportation system (STS) will increase the total useful tonnage it can place in orbit greatly during the 1980's. Conceivably, enhanced performance shuttles using stretched external tanks (ET's) could take to LEO over 160,000 pounds per flight. This total would consist of cargo contained in the shuttle and cargo compartments of the ET, the ET and associated fluids and propellants (7). We should remember how rapidly the Apollo system increased in capabilities between flights 11 and 15. Twenty enhanced STS launches per year could deliver as much mass to LEO (about 1,600 tons) as 16 Apollo launches. Regular and growing access to lunar materials could greatly leverage the value of these new LEO resources. Very likely the first uses of lunar materials would be on a relatively small scale (1 to 10's of grams per second). At this level lunar resources could substantially increase the effectiveness of an expanding space program (8). First

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uses might include shielding, bulk mass for tether systems, reaction mass or chemical propellants (see H.P. Davis or D.R. Criswell - this meeting). Regular access to the moon will permit extensive in-situ investigations using fixed installations and unmanned rovers such as the Lunohkods. Perhaps international research and commercial facilities which make advantageous use of the lunar environment can be established (8,10). Use of lunar and other non-terrestrial materials could significantly expand the scope of space exploration and settlement (11). Major increases in planetary explorations would be possible given routine lunar transportation and growing use of non-terrestrial materials such as propellant production at Mars or the Galilean satellites (12,13). An extensive annotated bibliography on space industrialization is available.

It is important to pursue open and extensive discussions of lunar science and exploitation. Major considerations range from more effective development of the present space science program (14) to establishing supportive government policies (15).

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FROM ANTARCTICA TO THE MOON: THE QUESTION OF EXTRAPOLATION, B.J. Bluth, Dept. of Sociology, California State University - Northridge, Northridge, CA, 91324.

It is obvious that there are similiarities and differences between small groups of people living and working at Antarctica and on the Moon. The question to be asked is how much has been learned or can be learned about the Antarctic that can be applied to developing stations of people living and working on the Moon.

First, we must examine the studies that have been done on the Antarctic. There are questions about the kind of data collected, methods of collection, the focus of analysis, the reliability of input, and the topics covered. Secondly, questions must be raised about the character and composition of the station crews and their relationship to potential Moon station members. Third, we must ask about the degree to which the isolation and conditions found in the Antarctic will be similar to those of the Moon.

One of the most significant assumptions to be questioned about the Antarctic data is that most of the symptoms that occurred were primairly a function of isolation and confinement. This may not be the case, and in fact, variables related to group organization, structure, training, communication with the outside, duty systems, stress factors, and health maintenance, in conjunction with psychological factors already looked at seem to indicate that many of the symptoms are not unique to isolation and confinement. The isolation and confinement may act as a catalyst in some respects, and it may have unique consequences in others. If this is the case, we can begin to identify steps that can be taken to enhance the quality of life on the station through by improving the kinds of conditions that are conducive to productivity, satisfaction , and thus the ability of crews to remain on the Moon for very long periods of time.

With the very important medical questions that remain to be answered about the ability of humans to live for long periods in a one-sixth gravity environment, it is premature to attempt to decide if early settlements should be permanent. However, there is much that is already known about group dynamics and structures that can lead us to begin to think about that question from a practical and realistic perspective.

The long term outcome may be that we can significantly improve the quality of life for the people living on the Moon and moving out through the galaxy, with a spinoff for those yet living on the Earth. Rather than let our social group systems be the result of random developments, we can use what we know to identify alternatives which can be chosen because of their practical consequences. That would be the development of a true freedom that comes from a base of knowledge and choice.

TOWARD A LUNAR RENAISSANCE

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This paper outlines needed technological, scientific, programmatic and institutional precursor activities for human return to the Moon. While we cannot forecast the exact combination of events that could lead to a rebirth of lunar exploration, we can confidently describe some of the elements that must be in place before a new manned lunar program can proceed. These are divided into four categories as follows:

1. Technological

Base development requires transport from Earth to Moon and return, long-duration support of human life on the Moon, and techniques for effective use of a permanently-occupied operating site on the Moon. Recent studies have placed emphasis on the use of lunar resources for all of these purposes. While not attempting a comprehensive review of all such proposals, this paper highlights their common technological elements as a guide to R and D projects that could and should be started now.

2. Scientific

Though a successful low-latitude manned lunar operation could probably be established on the basis of present scientific knowledge, additional knowledge would be very beneficial and perhaps essential. This paper summarizes important unknowns, with emphasis on the knowledge needed for establishing a polar lunar encampment.

3. Programmatic

Support of continuous manned lunar operations is clearly a major national or international activity requiring a level of effort equivalent to several billion dollars per year. Obviously we cannot forecast the political steps that could lead to such a commitment. Equally obviously, however, such a commitment will not arise from nothing - there must be a programmatic environment in which to cultivate it. This paper discusses early steps that might be taken to create such an environment. In the author's view the key step is to return to a state where lower-cost precursor missions are being launched by both the USSR and the United States. These missions could be either competitive or cooperative, but they are essential to provide a lunar focus. Third-party (ESA, Japan, etc.) missions, though important scientifically, lack this programmatic leverage because there is no serious prospect that their builders would proceed on to a continuous manned lunar activity on their own.

4. Institutional

None of the above steps can happen without the human resolve to do them, placing sufficient priority on them to make them compete with other desired activities. Providing training, encouragement and a communications focus for the young people who may lead the world in a lunar direction is thus another essential precursor activity. This paper discusses initial steps toward that goal.

INTERACTION OF HUMAN ALVEOLAR MACROPHAGES WITH LUNAR SOIL. J.H. Chalmers, Jr., M.L. Mace, Jr., S.D. Greenberg, Department of Pathology, E.C. Lawrence, R.R. Martin, Department of Medicine, Baylor College of Medicine, Houston, Texas, 77030.

Before colonization of the Moon by human beings can be realistically contemplated, potential deleterious effects of the lunar environment on human health must be considered. In particular, inhalation of noxious agents transferred from the lunar surface to the manned facility could be injurious to the lung. As a pilot study, we have investigated possible adverse effects of lunar soil particles on human pulmonary alveolar macrophages.

Pulmonary Alveolar Macrophages (PAMs), or Free Alveolar Macrophages (FAMs), are the major immunocompetent cells within the lung's airspaces, where they act as the first line of defense against noxious agents. These large phagocytic cells ingest and destroy foreign particles, as well as interact with other components of the immune system, (B and T lymphocytes), to regulate immune functions. However, certain environmental hazards in the Earth's atmosphere, such as asbestos and silica, are toxic to PAMs in vitro. This may partially explain the development of pulmonary fibrosis and/or lung cancer after asbestos exposure and pulmonary fibrosis after silica inhalation. To determine whether lunar dust might also be deleterious to PAMs, the following experiments were performed.

PAMs were obtained by bronchoalveolar lavage of non-smoking normal volunteers and were exposed in vitro to either lunar dust (Sample # 10084, 137), amosite asbestos fibers, or latex (as a control). Since expression of Ia antigens on PAM surfaces is essential for processing and presenting antigens to lymphocytes, effects of lunar soil, asbestos and latex (as controls) on Ia expression were determined. The percentage of PAMs expressing Ia was measured using murine monoclonal antibodies directed against the human HLA-DRW framework by indirect immunofluorescence.

The results obtained in three experiments with lunar dust are given below:

TABLE I

Agent Added

	Media Control	Lunar Dust (10 ug/ml)		
	0 hr.	1 hr.	2 hr.	24 hr.
Exp. 1	53*	34	36	64
2	40	66	49	-
3	50	68	46	-

*Data expressed as % Ia postive PAMs

Thus, short term (i.e., 1 to 2 hr) exposure to lunar dust had no demonstrable effects on Ia expression by PAMs. In a single experiment, 24 h cultures had no effects.

By contrast, similar concentrations of amosite asbestos markedly inhibited Ia expression, whereas latex had no effect.

TABLE II

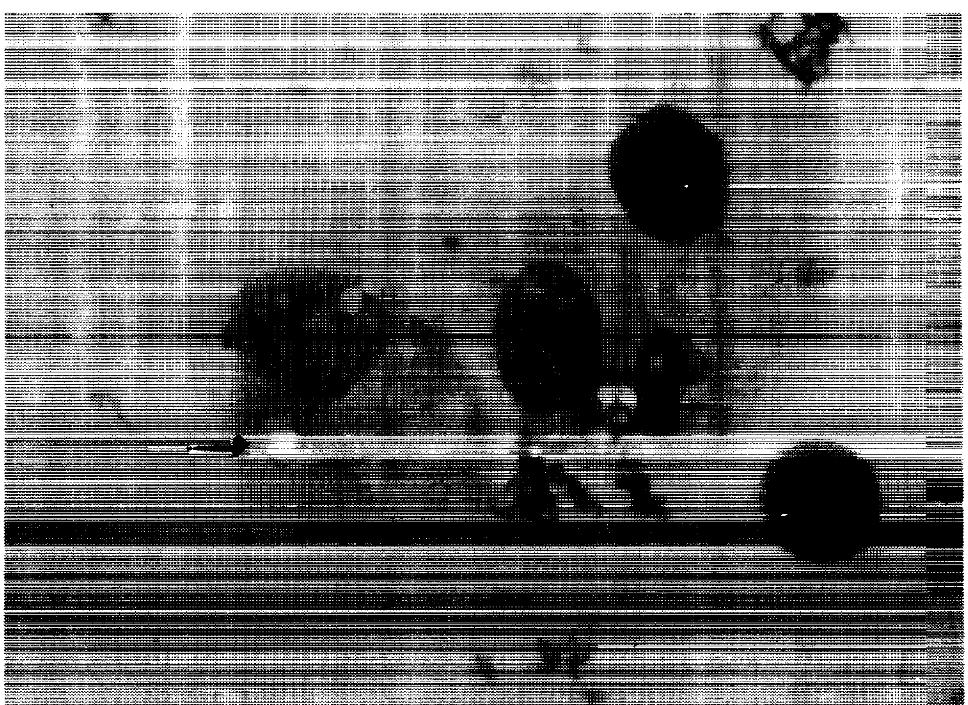
	Incubation Time (hrs.)				
	0	1	2	24	48
Media Control	58 ± 6	-	-	56 ± 8	55 ± 7
Latex (10 ug/ml)	-	58 ± 3	48 ± 5	57 ± 8	48 ± 4
Asbestos (10 ug/ml)	-	33* ± 8	31* ± 8	39* ± 7	46* ± 5

*p 0.05 compared to control

Phagocytic activity of PAMs toward lunar soil particles was examined by polarized light microscopy and SEM. Figure 1 shows PAMs which have ingested refractile lunar soil particles.

We conclude that no major abnormality of Ia expression or phagocytic activity could be discerned following exposure of PAMs to lunar dust. However, additional *in vitro* studies focusing on a variety of lunar dust interactions with the lung as well as *in vivo* studies with animals should be performed.

Figure 1



High magnification photomicrograph taken with polarized light. Note the ingested birefringent lunar dust particles (arrows), (Wright-Giemsa; x800).

TO THE MOON AND BEYOND: POLICY CONSIDERATIONS

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This paper argues that the next logical step into space would be to put that portion of the U.S. civil space program which is supported with Federal funds on an effective "pay-as-you-go" basis; that is, to see that the program (including and new major initiatives) provides 1) goods, services, and processes, 2) related international trade, 3) increased employment, and 4) an increased tax base, all of which, taken together, would be sufficient, in effect, to "pay for" continuing Federal civil space investments. The paper does not claim that scientific, military, national prestige, space leadership, international cooperation, and other space-related considerations are unimportant or unworthy of support; rather, the claim is that activities of these kinds could ultimately be stabilized and enlarged if it could be demonstrated to the American public that, overall, the publicly supported civil space program was increasing the Nation's material wealth. To that end, a much greater emphasis would be placed on applications programs, with the proviso that effective efforts would be made to involve potential financiers, as well as providers and users of services, both in the public sector and in the private sector, from the very beginning of any new applications projects. In this way, applications projects could provide the motive force for the entire civil space program.

A TRANSPORTATION AND SUPPLY SYSTEM BETWEEN LOW EARTH ORBIT AND THE MOON WHICH UTILIZES LUNAR DERIVED PROPELLANTS

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It is generally assumed that economically viable industries off Earth which utilize lunar or other non-terrestrial materials (NTM's) will require extremely large initial investments and possibly have to handle large quantities of materials per unit time. This may not be true. It may be economically advantageous to establish small facilities in low Earth orbit (LEO) and on the moon which can produce liquid propellants primarily from lunar materials. The lunar derived fluids would be used by both material supply rockets operating between the moon and LEO and by reusable rockets from LEO to transfer payloads elsewhere. Successful operation of the lunar supply system would almost eliminate the need for the space transportation system (STS) to carry propellant to LEO and thereby increase the useful cargo capacity of the STS.

Approximately 100 tons of lox-hydrogen propellant are required from Earth at a total cost in LEO of 0.2B$ per year to place 100 tons per year of payloads in geosynchronous orbit (GEO). Expendable rockets are used to accomplish the LEO-GEO transfer. Both the propellants and the expendable rockets occupy valuable cargo space in the space shuttles which could be put to other uses if the propellants could be provided from the moon. Thus, the total value of a lunar based transport system could be twice that of the costs associated with the propellants and expendable LEO-GEO launch vehicles the lunar system displaces. A permanent link would be created between LEO and the moon by which additional facilities could be transported economically to the moon as convenient. A successful lunar transport system might establish a lunar-LEO industry which could grow quickly and economically to much larger mass throughput levels (kilograms per second) to serve many other major industrial needs in space. Preliminary models indicate the lunar and LEO installations would have masses less than 5 tons and the supply rockets would require thrust levels the order of 20,000 newtons.

The proposed liquid propellants would be lunar derived liquid oxygen and silanes (chapter VI in ref. 1). Silanes are the silicon analogs of hydrocarbons in which the carbon atoms are replaced by silicon atoms. Theoretical calculations indicate that silane-lox rocket engines might achieve a specific impulse (300 - 350 seconds) similar to that of hydrocarbon-lox rocket engines (1,2). We assume that the hydrogen in lox-hydrogen rocket systems is provided from Earth.

The overall intent is to provide the largest amount of useful lunar derived materials back to LEO per unit of mass of hydrogen and ancillary mass provided from Earth to keep the lunar supply system operating. Let us refer to this ratio as the mass multiplication (MM) of the terrestrially supplied materials. Careful use of lunar materials are required to achieve MM in excess of ten with the proposed silane-lox system. Facilities on the moon would be engineered to beneficiate and refine lunar materials to obtain the maximum appropriate fractions of silicon and oxygen from the bulk soil for materials returned to LEO. Lunar derived materials would be formed into glass and ceramic components such as into one-use heat shields, tankage and other structures (3). On arriving in LEO both the lunar derived components and the bulk payload would be chemically processed into propellant fractions or used in other ways to support operations in LEO. In this manner the mass of equipment and consumables which shuttle between LEO and the moon is minimized.

On the moon the sophisticated operations of soil gathering and beneficiation, chemical processing (to produce silane, oxygen and a fraction of SiO_2), preparation and storage of cryogenic oxygen, and production of glass components using solar energy must be conducted. In addition the lunar materials must be loaded into lunar derived payload containers, the reusable rocket systems integrated with the lunar manufactured structures and the assemblies fueled and launched. In LEO the containers must be gathered following aerobraking maneuvers, propellants derived from the solid lunar products and the reusable sections of the transfer system sent back toward the moon. These are very difficult engineering challenges. If they had to be accomplished on a large scale at first to be useful they would probably be too expensive and elaborate to consider until relatively large manned bases are established on the moon for other reasons. Preliminary engineering studies allow one to estimate the masses of the required machinery (1,3,4). Somewhat less than 5 tons of equipment appears adequate to process the average of approximately 10 grams per seond of lunar materials required to sustain the LEO to deep space operations expected in the 1980's. The silane-lox rockets used in the transfer system could be used to emplace the lunar facility. The entire initial system, including propellants, could be taken from Earth to LEO in one shuttle flight. The lunar derived propellants might form the first materials industry off Earth which utilizes nonterrestrial materials, allows continual incremental growth and might be economically competitive compared to launching the equivalent products from Earth.

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LUNAR OXYGEN IMPACT UPON STS EFFECTIVENESS, Hubert P. Davis, Eagle Engineering, Inc., Houston, Texas 77058.

Many investigators have postulated constructive use of oxygen derived from lunar regolith material. The fundamental reason for considering lunar produced oxygen is the reduced gravity field of the Moon as compared to Earth. The lower gravity potential of the Moon can conceivably result in lunar-derived oxygen being made available to space flight activities at a lower cost than Earth-derived oxygen delivered to low Earth orbit by the Shuttle. Many of the earlier investigations of lunar-derived oxygen postulated the use of highly advanced propulsion systems, including the "mass driver".

In recent years, NASA, industry and university work on "Orbit Transfer Vehicle (OTV)" concepts have made significant progress. These efforts have been directed toward achieving a quantum improvement in the cost effectiveness of space transportation from low Earth orbit to geostationary orbit (GEO) when compared with the present solid rocket motor upper stages of the Space Transportation System. NASA and the USAF have recently embarked upon a program to introduce into the Space Transportation System (STS) a derivation of the "Centaur" oxygen/hydrogen upper stage for the Galileo, International Solar Polar and other missions. Advanced planning for the OTV has also investigated the use of the Earth's atmosphere to reduce Earth approach velocities on return from GEO to that of a low orbit space station with minimum use of the Orbit Transfer Vehicle rocket engine. This strategy has resulted in predictions of moderate improvement in cost-effectiveness of a space based cryogenic propellant OTV.

A new concept for carrying payloads to low Earth orbit with the Shuttle has evolved over the past 3 years, known as the "External Tank - AFT Cargo Carrier (ET-ACC)". Mr. Larry Edwards of NASA Headquarters has proposed an OTV to exploit this capacity. These developments along with recent work at the NASA Johnson Space Center on "Direct Insertion Space Shuttle Ascent" missions appear to offer a new opportunity for review of lunar oxygen utilization by OTV's based at a LEO space station.

The work to be reported at the March, 1983 LPSC includes a "first order" review of these new transportation developments and their influence upon the effectiveness of lunar surface produced oxygen. The initial results indicate that lunar oxygen is returned to a LEO space station in much greater quantity than the hydrogen fuel and other commodities required to be launched from the LEO space station to the Moon. If these initial results can be confirmed by subsequent analyses, establishment of a Lunar Surface Research Station might be fully supported by oxygen provided to the LEO station for use in OTV missions to GEO, planetary insertion trajectories and in support of national security needs. Conceptual description has been completed on a hydrogen/oxygen Lunar Ferry and a Lunar Module to accomplish the necessary maneuvers for lunar oxygen transport. Preliminary estimates of the performance of these vehicles have been made using a new

45 Kilonewton hydrogen/oxygen engine and an efficient aerobrake. When applied to present OTV designs, the resultant performance appears to render the use of lunar oxygen attractive without the use of more advanced propulsion approaches.

Further definition of all elements is needed before serious program planning or cost estimation can begin. The concept now appears to be sufficiently attractive to warrant additional work leading to a comprehensive system analysis and programmatic assessment.

LIFE-SUSTAINING LUNAR HABITATS
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The moon's composition has the same chemistry as the earth but lacks our gasses and water; however we can obtain hydrogen because of the peculiar conditions of the moon's regolith and obtain oxygen by melting oxide ores. With that availability of hydrogen and oxygen, we can reach the same beginning point in evolution which actually occurred in the development of life on earth; namely, hydrogen autotrophic bacteria which form the basis for cellular organelles and the development of the rest of the life forms, algae, higher plants, animals, fungi, etc. The sequence on the moon can be done much more quickly than occurred naturally on earth. On earth photosynthetic life forms emerged which get their energy from light photons and synthesize minerals from the soil. In both chemoautotrophic and photosynthetic life, the moon's dead soil is converted into life sustaining matter, that is water, gases and living bacteria or plants containing organelles, both are steps in the life chain.

Missions to the moon require fuel which could be replenished from this hydrogen contained in the moon's regolith, which is obtained by melting this lunar soil. Oxygen released from the oxide ores upon melting form the basis of a breathable atmosphere. Once melted, these oxide ores form glass which can be shaped into habitats offering radiation protection as well as a chamber to contain the gases and water vapor necessary for life.

BUILDING A LUNAR LABORATORY: A MULTIDISCIPLINARY HONORS STUDY, D. J. Evans, Lt. Col., U.S. Air Force, Department of Physics, U.S. Air Force Academy, Colorado Springs, CO 80840

Senior honors students in engineering and physical sciences at the United States Air Force Academy have studied the complex problem of establishing a permanently staffed laboratory on the moon. With minimal direction the students defined the scope of the project and established the goals and milestones for their work. The course was a true seminar with students sharing their ideas with each other and with guest speakers. This type of multidisciplinary study stresses sound analytical thinking and communicative skills as it offers a broadening experience for outstanding students.

The students prepared the rationale for returning to the moon and addressed the political, economic, and social value of a lunar base. They also studied alternatives in transportation, energy, structures, and life support systems and selected options for the first phase of a lunar research laboratory, achievable for a crew of 12 to 15 people by the year 2005. They have also outlined several research programs which need to begin now to meet this operational date for the base. These technology alternatives and program milestones will be presented with some rationale for their selection. In addition, the merits of this kind of honors seminar for undergraduate students will be discussed. The students' final report will be available for review.

ELECTRONIC UPSETS AND THE USE OF LUNAR RESOURCES

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Electronic failures on board space-based systems can be characterized as roughly falling into three categories: space-craft charging, single event upsets, and total dose effects. These effects are induced by either the products of solar flares or galactic cosmic rays (GCR). Electronic malfunctions of space-based systems have been studied for some time. However, the electronic component of these systems primarily have been of the small and medium scale integration (SSI, MSI) types. As our space systems increase in complexity and our dependence upon them grows, it is increasingly evident that their reliable operation must be ensured. Unfortunately as the complexity of these systems increases, the number of electronic device upset modes will also increase.

For example, the soft-error phenomenon is becoming an important problem for electronic systems flown in space. Soft errors are anomalous changes in the information stored in a semiconductor device without permanent damage to the device itself. They could represent a limitation on the capability of space systems. Soft errors must be avoided through proper choice of circuit components, software, and/or shielding. It is the last approach, for reasons that will become clear through the remainder of this paper, which we will advocate as a solution to this potential problem of space development.

The first evidence for charged particle induced electronic upsets in space-based systems came from the simulation studies of Binder et al.(1) Binder gave evidence that the soft errors previously exhibited by bipolar digital components in space systems were the result of the passage of a heavy cosmic ray nucleus ($Z \geq 26$) through one of the circuit elements of the device.

Since 1975 there has been an increasing amount of attention given to the soft-error phenomenon. In addition the error rates observed on satellites have increased significantly, presumably as a result of the introduction of large-scale integrated (LSI) devices.(2)

The decrease in volume occupied by each logic element on the LSI chip results in a corresponding decrease in the amount of charge required to differentiate logic states of the element. The radiation sensitivity of these devices is such that alpha particles emitted from contaminants embedded in the plastic lids of these devices have been implicated in problems of terrestially based electronic systems. Furthermore, another mechanism, dose rate (i.e., multiple event upset) is being studied at the Los Alamos Meson Physics Facility (LAMPF). Experiments there demonstrated that relatively minor solar flares can produce dose rates sufficient to upset electronics of the LSI variety. For example, spacecraft with 10^5 bits of memory, distributed in 25 memory devices (4K RAM) flying in a region of deep space characterized by a proton flux of 2 p/cm^2-sec would exhibit anywhere between 0.04 and 4 proton induced soft errors per day.(3)

Three primary types of energetic ions are of concern from the standpoint of radiation damage because they are encountered in near-earth space. The first is galactic cosmic radiation which is primarily protons, although α-particles, medium mass ions, and even heavy ions ($Z \geq 20$) are present in the GRC population. These ions have very high characteristic energies (1-10 GeV/n; n nuc.) and are continuously streaming into the near-earth region from outside the solar system. At 1 A.U. the galactic cosmic rays seldom have energies less than a few hundred MeV; particles with energies between this lower energy bound and a few GeV are strongly modulated with the 11 year solar cycle. At solar activity maximum the galactic cosmic ray flux lowest, while at solar minimum the flux is greatest. A typical GCR flux (E >100 MeV) might be 1 p/cm^2-s with a differential spectrum following off as $E^{-2.5}$.

A second type of energetic ions encountered in space are the solar cosmic rays (SCR) or solar flare particles. These particles are not present continuously but rather are emitted sporadically from the sun during burst-like solar flares. Solar flares occur frequently at the peak of the 11-year solar activity cycle, but they occur very infrequently during the solar activity minimum.

Solar flare particles have energies between $\sim$10 keV/n and several hundred MeV/n and have a steeply falling variable spectrum

$$\frac{dJ}{dE} = KE^{-\gamma}; \; 2 \leq \gamma \leq 4$$

In an average flare, the typical flux of protons with E >10 MeV might be $\sim$100 p/cm^2-s.

Solar flare particles can readily penetrate into the outer portions of the earth's magnetosphere and thereby permeate most cislunar space. For example, measurements made with Los Alamos instruments at geostationary orbit during a particular flare in the rising phase (September 19-20, 1977) of the present solar cycle showed that E >50 MeV solar proton intensities were >5 $cm^{-2}s^{-1}$ for over 30 hours. During the time from the last solar maximum (1979-1980) to the present, similar solar flare effects have occurred typically once or twice per month. A notable series of recurrent solar flares (27-day period) due to one active region on the sun has produced solar proton events for more than 10 months beginning in late 1981. A well-studied example of this series of flares showed maximum solar particle effects on 13 July 1982. The peak detected flux was 3 x 10^4 p/cm^2-s. The total proton fluence above 10 MeV on this day was 10^8 p/cm^2. Using the soft error upset rate model cited above, such a proton environment would produce between 20 and 2000 soft error upset per day in just one LSI satellite system, and this for a relatively small memory capability.

Solar flare effects can be even more pronounced than these typical numbers illustrate. In the August 1972 flares, for example, the peak proton intensities (E >10 MeV) were >2 x 10^5 p/cm^2-s. In this series of flares, the omni-directional proton flux above 10 MeV exceeded 100 p/cm^2-s for more than six continuous days. This type of flare activity would be expected to produce 10's or 100's of soft error upsets per day in typical present-day LSI space-based systems.

A third type of energetic ion radiation encountered in space is the trapped Van Allen radiation. Significant fluxes of protons with E >10 MeV are confined to altitudes $\leq$18,000 km.(5) The peak trapped flux of >10 MeV protons is $\sim$3 x 10^5 p/cm^2-s at several thousand km altitude in the magnetic equatorial region. Obviously, the trapped energetic proton component, which is continuously present, only affects spacecraft in relatively low earth orbit; spacecraft passing through this region would, however, be expected to experience large numbers of bit errors.

Near-earth space has come into increasing use for a number of important human endeavors. At present, nearly all of the developed countries, as well as many of the developing countries are relying upon spacecraft at the geo-stationary orbit (36,000 km altitude) for communication purposes. This communication, both military and commercial, may be expected to increase substantially in volume within the next two decades.(6) Because of limited useful frequency bandwidth for such communications, increasingly complex electronic solutions (e.g. multiplexing) will have to be employed. This clearly suggests increasing complexity of communication hardware and an increasing use of LSI and/or VLSI technology in order to remain within reasonable size parameters for free-flying geosynchronous satellites.

Gelfand, E. M., et al.

A . fraction of the U.S. national security capability is vested in space-based systems. Military reconnaissance and treaty verification instrumentation is presently flown on board cislunar spacecraft. In general, the C^3I (command, control, communication, and intelligence) function is being subsumed into the U.S. space program. An example is the GPS (Global Position Satellite) program which has as its program goal the allowance of field unit geographical positioning to within 10 meters anywhere on earth. Again, as in the commercial communication area alone, C^3I will, of necessity, rely quite heavily upon very fast space-based processors (LSI, or greater) to achieve its objectives. Furthermore, in this crucial national security arena, survivability and uninterrupted operation of C^3I systems will be of paramount importance. These systems will have to be protected from solar and galactic cosmic rays by means of adequate shielding.

Large information storage and processing systems in cislunar space, used for communication and national security purposes, will eventually be used almost exclusively since no other system will meet the requirements in these areas. Consequently, it will not be possible to tolerate even brief outages of these systems due to increased hostility of the natural environment. Passive shielding of VLSI installations in space would be possible using materials ferried into space by the STS (shuttle) or its successor. However, if a lunar research laboratory(7) has already been emplaced, then the lunar surface would provide a natural, and energetically favorable, source of materials for VLSI installation shielding.

A lunar communications base could be readily protected from SCR and GCR through the use of lunar regolith as shielding. Most SCR particles are stopped within the upper few cm of lunar soil and nuclear reactions induced by GCR particles affect soil only to a depth of several m (see review papers by Reedy(8) and Crozaz.(9) Crozaz(9) notes that galactic protons and heavy ions (Z >20) have penetration depths of 400 and 40 g/cm^2, respectively.

Area(s) selected for a lunar communications base or bases should have very thick regoliths consisting of high-density lunar soils. The regolith should be easily quarried and moved with minimal energy expense for the purpose of burying structures housing electronics. Two types of lunar provinces meet these criteria:

(1) The older Maria where regolith of basaltic composition is most mature. For example, regolith thicknesses of greater than 4 m and higher density (>1.5 g/cm^3) can be found across most of Mare Serenitatis.
(2) The lunar dark mantle deposits, such as those described at the Apollo 17 site, are most ideal for shielding a lunar base for several reasons. Based upon seismic data at the Apollo 17 site,(10) crater counts and sample analysis(11,12), the dark mantle deposits have a pyroclastic origin and form thick, high-density (2.04-2.3 g/cm)(13) clastic deposits underlying a mature regolith. The use of these deposits as shielding would offer maximum protection per meter of "regolith" and maximum thicknesses (tens of meters) of clastic material easily quarried and transported. Distribution of dark-mantled deposits has been summarized in a review paper by Head;
(3) Possible locations cover thousands of km^2 on the lunar nearside, including well-characterized areas in southwestern and southeastern Mare Serenitatis.

Summary

It can be seen that dependence on space-based systems could be placed at risk by the space environment because of the increased capabilities of those systems. In this case we have seen that the electronics on board our space systems are vulnerable to a number of charged-particle-induced transient upsets. Although there may be technologies which are less susceptable to these upsets (e.g. GaAs and Integrated Thermionic Circuits (ITCS)) they do not as yet exist. Thus we believe a solution to this problem can be found in the judicious use of available lunar resources.

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THE INTERNATIONAL LAW AND POLITICS OF MOON SETTLEMENTS. Nathan C. Goldman, Assist. Prof. of Government, University of Texas, Austin, Tx. 78712

Whether we go to the moon alone or in consortium with other countries, returning to the moon will have a major impact on world law and politics. Since we went to the moon, a large body of space law has developed which will affect every step of our return--the trip, the base, our obligations to our space partners and the rest of the world. The return will ultimately have a reciprocal effect on that law, as practical experience renders some practices obsolete and exposes new, unconsidered problems.

The United States is a party to four treaties, drafted by the Committee on the Peaceful Uses of Outer Space (COPUOS) and confirmed by the U.N. General Assembly. A fifth treaty, the Moon Treaty, was also drafted by COPUOS and confirmed by the U.N., at this writing, the Treaty has not been accepted by enough nations to become effective(1); moreover, the U.S. Senate, in 1980, refused to ratify it. The Treaty seems destined to be ratified by non-space powers and to have only a quasi-legal existence in customary international law.(2) All five treaties will regulate human activities on the Moon and other celestial bodies.

The return to the moon would be a permanent one. Four options are: a worldwide expedition; a Western consortium; the U.S. alone; and a private endeavour. The first is unlikely because of politics; the fourth, because of costs and profits. The consortium option, probably including Japan, Canada, and the European Space Agency(ESA), may be the most likely.

Although the U.S.'s reneging on our part in the International Solar Polar Mission (ISPM) made Europeans leery of cooperating with the U.S., experience with Spacelab and space station follow-ons will provide the legal and political framework for cooperation on lunar exploration and exploitation.

The 1967 Outer Space (Principles), 1971 Liability, and 1975 Registration Treaties provide the bases for determining duties and obligations between partners and towards third parties.(1) Article II of the Registration Treaty envisions the situation:

> Where there are two or more launching States in respect of any such space object, they shall jointly determine which one of them shall register the object (with the U.N.), bearing in mind...article VIII of the Treaty on principles..., and without prejudice to appropriate agreements concluded or to be concluded among the launching States on jurisdiction and control over the space object and over any personnel thereof.

In addition to apportioning control, the launching states can also apportion liable among themselves. Nevertheless, each "launching state " remains "jointly and severally" liable for damages to a third party on earth, in air, or in space.(Article VII, Principles Treaty; Article IV, Liability Convention.) If accidents cause damage on earth or in the air, launching states are absolutely liable; however, if damage occurs in space (including the Moon), liable is assessed by fault.(Article IV, Liability Convention.) Of course, the consortium can agree beforehand on how to arbitrate claims among its members. The Liability Convention, however, becomes more important as other settlements on the moon come into conflicts.

Accidents or deliberate actions could precipitate such conflict. The 1967 Treaty requires nations to "undertake appropriate international consultation before proceeding" with any activities that could "cause potentially harmful interference with the activities of other States Parties."(Article IX.) The Moon Treaty, Article 7, would mandate an even greater responsibility for moon settlements: "States Parties shall take measures to prevent the disruption of the existing balance of its environment...." Openning up mining installations, or nuclear or genetic research facilities on the moon would activate these provisions.

NASA has funded studies on the engineering of moon-mining operations. (3) The project is do-able, but can it be profitable? A small but central part of the answer must deal with the legal status of the project. The 1967 Treaty decided that no one could own the moon, and that it would be open to all. (Article I.) The Moon Treaty, more specifically, denominates "the moon and its natural resources" as "the common heritage of mankind."(Article 11.) No state or corporation can own the "natural resources in place;" moreover, the Treaty obligates its signatories to "undertake" to establish an "international regime" to regulate operations.

The U.S. negotiators argued that "in place" provision permitted mining of celestial bodies without moratorium; likewise, the provisions for an international regime would not create any interim moratorium, nor would the regime prohibit private operations in space.(1,2.) The Senate rejected the Treaty, nevertheless, largely because of these ambiguities. The resulting uncertainty still clouds any lunar activities and positively blocks any private actions.

This abstract just touches on a couple of legal problems (none in detail) which may confront those planning a return to the moon. These legal requirements will greatly affect political decisions on the arrangements for returning to and using the moon. The legal options should be thoroughly assessed to permit the broadest, most advantageous, and peaceful exploration and exploitation of the moon for the benefit of all humanity.

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THE POLITICS OF RETURNING TO THE MOON: IS 2007 A REASONABLE TARGET? Nathan C. Goldman, Assist. Prof. of Government, University of Texas, Austin, Tx. 78712.

The simple, cryptic answer is that 2007 is too conservative and too liberal a target for returning to the moon. Full answer requires assessment of policy making in general and of space policy in particular. Presently, at least three models have been used to explain policy making. The oldest, incremental decision making, assumes that decisions are achieved through incremental additions to or subtractions from the status quo.(1) This model, however, does not well explain new projects or major changes in old ones. Studying the building of the shuttle, Schulman developed a nonincremental model of decision making.(2) Schulman argued that big projects needed "critical mass" of public support before they would begin. Moreover, size of projects created inertia that made further changes difficult.

Approaching decision making differently, Logsdon posited "crisis" decision making models to explain the decision to go to the moon.(3) Logsdon focussed on external factors which force government to act quickly. Yet, he found that even in crisis, decision makers could proceed boldly only if they had preliminary plans and consensus on feasibility. Both conditions existed in 1961. NASA had a ten year plan which NAS and other experts considered workable. Supportable plans for returning to the moon are paramount. As demonstrated with MX basing, "critical mass" support is not easily attained.

Only under the incremental model can one assume or predict any straightline development towards moon settlements by 2007. All three models, moreover, require an assessment of the political forces which might create "critical mass" support or "crisis" response.

The scientific community, especially the astronomers, are the most concerned interest group. Augmented by the 120,000 members of Sagan's Planetary Society, the astronomy community may actually have some political muscle in addition to their political standing as experts. Arguments of astronomers or planetary geologists-- studying origins of planets or building radio telescopes unannoyed by earth interference-- will not justify the mission politically, and might create political backlash among diverse groups concerned with budgets or with social programs.

The military is a second group which might support a return to the moon. The 1967 Outer Space Treaty, however, forbids military installations on the moon, so military interests in the moon would be secondary--a site for resources or observation. (4) Moreover, even this military interest might generate fear among segments of the public and create opposition. The connection between Apollo and the Cold War, during the anti-Vietnam/ detente era, contributed to NASA's hiatus in the 1970's. (5)

Another element of "critical mass" support is the citizen's pro-space lobby. This phenomenom is less than a decade old and is composed of almost one hundred diverse groups. The following table shows that this lobby, especially when aligned with the science fiction groups, has a sizeable following:

TABLE: CHARACTERISTICS OF THE SPACE CONSTITUENCY*

Government Employment	10,000
Pertinent Aerospace Industries	100,000
Trade/Professional Societies	50,000
Citizen Space Societies	125,000
Citizen Space-Related Societies	100,000
Citizen Science Fiction Groups	100,000
Readership of Space-related Magazines	1-5,000,000

*Estimates prepared for the Anderson for President's Campaign, 1980

The lobby did change the name of the first shuttle to Enterprise (1977), helped save the Galileo mission(1978), and organized the fight to kill the Moon Treaty(1980); however, none were big money projects, and the lobby would not have the strength to pass a lunar return through the Congress.(6)

The goal of the space community,therefore, must be to build public support for returning to the moon. As Krugman has shown, public support for NASA has varied depending on economic conditions, perceived benefits of space, and on-going events in space. In fact, one of the highest support ever for space, 70%, was recorded after the fifth shuttle flight which demonstrated the commercial applications of the shuttle to the public.(7)

The bottom line on the moon, thus, seems to be combining mining, colony, laboratory, and applications as well as a control center for cislunar space. Science wins few votes; escapism, a few more. Security can win more, if the moon were demonstrably important militarily. But Selling space, especially the moon, will require convincing the people that the moon is politically and economically important and urgent. Cost/benefit studies need to be prepared to determine if the moon is the right goal at the right time.

Building plans and support must go hand-in-hand. If one accepts the nonincremental model, preparation of "critical mass" still requires slow incremental development of a viable plan and its support. If a "crisis" arises, such as Russians or Europeans establishing a mining base and underselling earth-based ores, the U.S. would need a plan.

Because no one can predict when decision makers will face situations requiring specific decisions, one cannot know whether 2007 is realistic. Planning, however, is reasonable because it is the first necessary step in its fulfillment.

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MATERIAL RESOURCES OF THE MOON. Larry A. Haskin, Dept. of Earth and Planetary Sciences & McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130.

The escape velocity from Earth is 11.2 km/sec and from Moon is 2.4 km/sec. Thus, an object must be given some 20 times more energy to move it from Earth to high orbit than from Moon to high orbit. In fact, the practical energy difference is probably at least twice that, since transport from Earth requires lifting and acceleration of the transporting rocket and its fuel over a substantial distance, whereas lunar mass drivers (1) may be able to release payloads at escape velocity directly from Moon's surface. Thus, if large structures are to be built in orbit or on Moon's surface, the potential savings in energy cost is a strong incentive to use lunar rather than terrestrial materials for their construction, provided that suitable lunar materials can be produced cheaply enough. Also, in light of decreasing ore grades, increasing energy costs, and environmental problems here on Earth, it is conceivable that an efficient means of processing could lead to use of lunar materials here on Earth.

Economical use of lunar matter might involve only a single product, for example, unprocessed lunar soil to provide shielding against solar flares for personnel and equipment. More likely, it will depend on a spectrum of products, including glasses, ceramics, and metals. This possibility depends on what resources are available from Moon, on what processes are developed to refine them, and on how much supplementary material must be provided from Earth.

Initial assessments of lunar resources (2) are based on some major constituents of lunar rocks (Si, Fe, Mg, Al, O), plus Ti from some mare lavas, meteoritic Fe-Ni in soils, with a weak case for obtaining Cr, Mn, S, and P of igneous origin, plus small amounts of C, H, N, and noble gases from implanted solar wind in lunar soils. The possibility for water, carbonaceous material, sulfur, and halogens in permanently shadowed areas is recognized but untested. Most other elements are regarded as too dispersed to be of use.

This assessment, while encouraging, may be too conservative. It has roots in the notion that Moon's igneous differentiation was dry and produced only a few products. On Moon as on Earth, the bulk of most chemical elements is dispersed at unusably low concentrations in common rocks. Most terrestrial ores occur where some geochemical separation process has been driven to extremes in a specific locality. This extreme usually involves action of aqueous or perhaps carbon dioxide rich fluids. Moon, lacking these volatile materials, presumably cannot produce pegmatitic, hydrothermal, or low temperature sedimentary ores.

Lunar samples nevertheless reflect a variety of geochemical separation processes. In igneous rocks, Cr bearing spinels and Ti rich minerals are observed to form and, being dense, could accumulate locally into concentrated ores. Relatively volatile elements such as S, halogens, Pb, Cd, Ag, As, and Sb are vaporized, apparently both by fire fountain volcanism and by meteoroid impact, and are concentrated manyfold over average rock contents as surface coatings or in breccias. Rusty rocks indicate the presence of crystalline $FeCl_2$. Mobilized sulfides have been injected into some impact breccias; in some cases these may be enriched in sulfide soluble trace elements. Rare earths, Th, U, P, and other elements are enriched in some breccia clasts by 40 times their average concentrations in surface soils; this includes KREEPy as well as other patterns of enrichment. Lunar granites exist but the mechanism by which they formed is unknown. Thus, it is clear that strong separation processes do occur on Moon. These processes are not well understood, but have produced compositional variations that are substantial by terrestrial standards and may well have produced ores on a local scale. It is important that we improve our understanding of these processes. Terrestrial exploration strategies are based in part on current ideas of how differentiation processes work on Earth; the same will surely be true on Moon. In addition, effects of impact mixing and dispersion of ore bodies on Moon deserve consideration.

Terrestrial exploration strategies are also based on empirical discoveries of ores. In this regard, although we know enormously more about Moon than about any other planet except Earth, Moon remains largely unexplored. Each new mission, right down to Luna 24, brought surprises in rock type and composition. Recent detailed studies of breccia clasts, spurred in part by attempts to attain mass balances for soils, are expanding the number of distinct types of highland igneous rocks identified, now at least 15. Lunar igneous differentiation was far more complex and interesting than envisioned in early models, for example in the main features of magma ocean crystallization. The fraction of Moon's surface that has been sampled is very limited. Apollo orbital data provide some insight to compositional fluctuations for $\sim$ 20% of the lunar surface, but spatial resolution and detector resolution do not allow confident extrapolation of ground truth sample information to these regions at an optimum level for resource survey. A sampling of terrestrial igneous rocks to an extent analogous to that for lunar rocks would be unlikely to reveal the presence of ore bodies on Earth. Failure to observe ores so far in lunar rocks is not surprising.

Even given the worst case situation, that there were no better ores than the rocks already known and that only Fe, Ti, Al, Si, Mg, and O are available in usably high concentrations, the variety of possible products still makes use of lunar material promising (3). The best processes to use for refining these materials remain as unexplored as Moon itself. One approach is to package known terrestrial methods for use in the lunar environment. This approach requires very high yield recycling of Earth produced reagents. It treats the lunar environment (no cooling or oxidizing atmosphere, no running water, no expendable supplies of prepared chemicals, no Earth-like ores, very long days and nights) as a barrier to be overcome. Processes that take advantage of the lunar environment deserve at least equal attention. The presence of trapped water or other volatiles on Moon's surface would affect substantially our considerations of what processes to pursue.

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HUMAN LIFE SUPPORT SYSTEMS ON THE MOON: SOME ECOLOGICAL CONSIDERATIONS,
Bassett Maguire, Jr., Department of Zoology, University of Texas at Austin, Austin, TX 78712.

In the long term, if not in the short, human life support sytems most likely will be primarily biological. Preliminary considerations of the most simple requirements for the people and for the necessary agro-ecosystem are discussed. Based on the list of plants considered by a group of (higher) plant physiologists to be the most important candidates for this agro-ecosystem, the per person per day requirements are approximately: 190 kg of water for the transpiration of the plants, and 2354 g of carbon dioxide to support the plants' photosynthesis. A total of about 615 (dry) g of food and 912 (dry) g of non-edible plant parts will be produced. The plants will produce about 1712 g of oxygen as a byproduct, and the amount of space required (per person) will be about 82 m^2 (including walkways between crop beds or vats). These numbers assume a completely vegetarian diet; a small amount of additional space (about 2 m^2 per pair of rabbits, for example) will be required to provide a balanced diet (and one which contains all of the needed components, vitamin B_{12}, for example).

Some of the effects of cutting off of an (agro)ecosystem from the normal dynamics of the earth also will be discussed (along with suggestions concerning how to nullify those effects which are deleterious).

THE MOON AND ANTARCTICA; Hans Mark, Deputy Administrator, National Aeronautics and Space Administration, Washington, DC 20546

The moon is remote and the environment there is hostile. The same can be said about the continent of Antarctica. Is there any analogy that can be drawn between the history of what has happened in Antarctica and what will happen on the moon? The exploration of Antarctica can conveniently be divided into three phases--early exploration, scientific expedition, and the establishment of a permanent presence. Each of these steps were taken for somewhat different reasons, and, if the analogy is valid, then perhaps some extrapolations can be made to what will happen on the moon.

A MANNED LUNAR BASE AND THE NASA BUDGET: IS THERE ROOM FOR ANOTHER PIG IN THE PYTHON? W. W. Mendell and M. B. Duke, NASA Johnson Space Center, Houston, TX 77058

We have argued that a manned research laboratory on the surface of the Moon is part of NASA's future and, in particular, that NASA must begin very preliminary work now (1). Any version of the Space Transportation System (STS) which can service geosynchronous orbit also can service lunar orbit because the energy requirements for the two types of missions are very similar. After maturation of the STS, lunar exploration and exploitation is a certainty at some point because such projects will present only modest technical challanges. Within the next ten years elected officials will become aware that manned lunar activity is very much an evolutionary extension of the STS. A declaration of a national committment to return to the Moon will become a viable political option.

Needless to say, such a declaration would have tremendous significance for NASA. Unfortunately, the space agency has a recent history of being ill-prepared when possible opportunities for new initiatives arise unexpectedly (2). We propose here a programmatic approach which will permit NASA to perform a thorough and realistic evaluation, in the early 90's of a possible manned lunar laboratory. We require no new funding for what will turn out to be the first step in a three-part program to return to the Moon.

We assume the NASA budget will be approximately constant in real terms over the next ten years. We also assume that the budget will continue to be programmed as it has been historically. The greatest part of the budget will go to a major project associated with manned spaceflight, e.g. Apollo, Shuttle, or Space Station. A minor but significant fraction will go toward space science. In FY83 the space science programs (physics and astronomy, planetary, life) consume approximately 1/8 of the total research and development budget. Over the past 15 years planetary science and physics & astronomy have summed to more that 90% of the space science budget (3). The proportion going to each of the two large programs has varied, depending on mission costs. In FY74 77% went to planetary (Viking); in FY83 67% goes to physics and astronomy (Space Telescope). We assume that 40% to 70% of the total space science budget could be allocated to planetary science over the next ten years if there were valid programmatic reasons for doing so.

Under our stated assumptions we propose the following programmatic thrusts, requiring no additional funding over the next 7 or 8 years. First, prepare the necessary information base concerning the Moon in suppport of detailed definition of the lunar laboratory program. Data would be collected by a long-lived unmanned satellite in lunar polar orbit. Second, a lunar research and analysis program must be maintained, with special emphasis on lunar resource utilization. Third, a coordination point for lunar laboratory requirements and studies must be established in NASA Headquarters. A possible fourth element involves decisions regarding the design of the OTV/lunar ferry. If the arguments presented by Davis (4) are valid, and oxygen produced from lunar materials in situ could double or triple the payload capacity of the Shuttle fleet, then the development of an efficient hydrogen-oxygen vehicle becomes an important issue.

The Earth and Planetary Exploration Division (EPED) in NASA Headquarters has been studying future planetary programs with the aid of a scientific advisory group, the Solar System Exploration Committee. As a result of these deliberations, the current EPED strategy emphasizes small missions to the terrestrial planets. First priority goes to a Venus Radar Mapper (VRM). A lunar geochemical orbiter is included in the proposed core program, but its priority seems linked to an assumed commonality with a Mars geochemical orbiter.

We argue, of course, that the lunar mission has a higher priority and that it should be given a new start as soon as possible, in FY85. A launch could take place in the late 80's and the new data base would be available in the early 90's for planning a manned surface laboratory. The planetary programs budget could accomodate both VRM and the lunar orbiter because both missions are much less costly than Mariner-class missions in the 70's. At the present time EPED is unable to consider such arguments because the organization is chartered to develop exploration strategies based only on scientific rationale. Thus the first element of our program, which can be accomplished by simple rearrangement of priorities, can be implemented only if decisions on the importance of lunar studies are made at the Associate Administrator level or higher.

The second element of our programmatic approach is the maintenance of a healthy lunar research program with special emphasis on lunar resource utilization. Studies associated with the lunar orbiter mission would be sufficient to stimulate lunar science. However, very little work is being done on the potential exploitation of lunar resources; and an infusion of research funds on the order of a million dollars would have a dramatic effect on utilization studies. A funding enhancement of that order would be insignificant in the total NASA budget.

The establishment of a manned lunar laboratory is a complex enterprise whose requirements will impact every part of NASA's research and development organization. As a space station is designed,

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as a lunar orbiting spacecraft is developed, as advanced propulsion systems are considered, choices are being made which can affect a future lunar base program. For example, good maps of the Moon might be important for siting a lunar base; yet cartography ordinarily would not be part of the science package for a lunar orbiter. The economic advantages of oxygen for fuel imported from the Moon would be lost if the OTV is not a H_2-O_2 vehicle. Some arbitrary payload limit on an OTV design could preclude its use as a lunar ferry. Is there an orbital inclination for a space station which would optimize its performance as a node in the lunar transportation system? Storage of cryogenic fuels in space becomes a more pressing technological issue when the significance of the lunar connection is understood.

These considerations demonstrate the need for an active coordination function for lunar base requirements within NASA Headquarters, the third element in the first phase of the lunar initiative. Since no major funding can be made available for that function, it must reside in an advanced planning office and it must carry the Administrator's blessing. Once established, the coordination office should sponsor a blue ribbon workshop to establish the validity of a lunar presence as a national goal and to outline the tasks to be accomplished for an eventual return to the Moon. We already are aware of leaders in government, science, and the technical community who would be interested in participating in such a workshop. After the initial requirements are identified, low level funding should be available for studies of specific issues as well as the important work of coordination within NASA. We have discovered groups around the country who are interested in studying specific issues without funding and who ask for relevant problems to work on (e.g. 5).

At the end of the first phase of the lunar initiative in the early 90's, the American space program should possess the scientific information and technological elements necessary for a realistic appraisal of the lunar option. We believe that an increased understanding of the Moon's potential will make it an economically and politically attractive national objective. Exploration of the Moon will yield rich scientific dividends and will contribute to a new optimism in America with regard to her technological capabilities.

The second phase of the lunar initiative will bring unmanned roving vehicles to the surface of the Moon for site evaluation, civil engineering measurements, and sophisticated scientific experimentation. Development of the lunar transportation system will take place, and automated factories will be placed on the lunar surface to initiate economic utilization of lunar materials prior to the establishment of a permanent manned presence. From the second phase we will gain experience operating in the lunar environment, learning the advantages and the difficulties.

The third phase of the lunar initiative will see the establishment of a permanent manned base in time for the Fiftieth Anniversary of the Space Age. The first habitat module will be landed at a location where an automated factory is already producing oxygen from lunar soil. A remotely controlled earth mover, the last launch in the Phase Two robotic exploration, is also there. After the module is dragged to the specified site in a small depression, it is covered with soil for protection from solar flares. Over the succeeding months, other specialized modules are landed, and the initial crew of 12 gradually grows. As research facilities come on line, scientists are brought from all over the world, after survival training, to perform proposed experiments in astronomy, high energy physics, geology, and life sciences. Live television coverage will bring the people of the world in contact with activities on the Moon. As life becomes routine and the exotic flavor passes, school children will wonder why anyone ever doubted that the Moon would be an integral part of our destiny.

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WHY ARE YOU TALKING ABOUT A MANNED LUNAR BASE NOW WHEN THE SHUTTLE FLEET NEEDS A FIFTH ORBITER, WHEN THE SPACE STATION PROJECT IS SPUTTERING, WHEN PLANETARY EXPLORATION HAS HAD NO NEW START SINCE 1978, WHEN THE NATIONAL ECONOMY IS IN THE WORST SHAPE SINCE THE GREAT DEPRESSION, WHEN THE JAPANESE ARE PUSHING FOR WORLD LEADERSHIP IN TECHNOLOGY, WHEN THE SOVIETS AND THE EUROPEANS ARE CHALLENGING AMERICAN PREEMINENCE IN SPACE, AND WHEN VIDEO GAMES ARE CORRUPTING OUR YOUTH? W.W. Mendell and M. B. Duke, L.B. Johnson Space Center, Houston, TX 77058.

For the past 15 months we have been speaking in various forums within NASA and in the space science research community concerning the need to begin preparation now for a decision to establish a manned research laboratory on the surface of the Moon. Before the end of the next decade, the Space Transportation System (STS) will include a space station and a reusable Orbital Transfer Vehicle (OTV), the latter for the transfer of payloads between low Earth orbit and geosynchronous orbit. The energy requirements for a transfer to lunar orbit are very similar to those required for transfer to geosynchronous orbit. The existence of that capability will force the question whether a permanent manned presence on the Moon's surface falls within the national interest.

In fact, this "minimal" scenario is almost certainly too conservative. As space activity becomes more commonplace in world affairs, awareness of the lunar option will emerge well before the turn of the Century. We have no difficulty imagining motivations for a significant American enterprise in space stemming from international economic competition, cold war geopolitics, or national security considerations.

Consider the economy of the United States, now in the throes of transition. In the important arena of international trade, the country must depend more on the export of technology, a word once automatically associated with the adjective "American". Today the Japanese are making inroads on American leadership using long range planning and efficient management of goal-oriented technology development. The relationship between business and government is so different here that it is difficult to respond to the Japanese thrust in kind. The traditional American method for priming the technological pump has been government financed projects in science or engineering, designed to demonstrate the American fortè - organization and management of high technology. A manned research laboratory on the Moon is a world-class project which would serve nicely to stimulate innovation in the private sector.

The political impact of this project would be significant, both nationally and internationally. An analogy to 1961 could be drawn when the declaration of Project Apollo was a political reaction to the national preoccupation with Sputnik and the demoralizing effects of the Bay of Pigs. Today the American public largely discounts the methodical Soviet space program, which is not the unknown quantity it was 25 years ago. Nevertheless the imminent development of a very large Soviet booster probably will lead to a highly visible manned mission. A re-enactment of the fable of the Tortoise and the Hare, coupled with some domestic or international difficulty, could make a lunar initiative politically attractive. It is important to remember that today the lunar option is much more an evolutionary development of the American space program than it was in 1961. Ironically, we are much farther away from going to the Moon today than we were in 1961.

The current space budget of the Department of Defense exceeds that of NASA, testimony to the importance of national security considerations in space policy. Any major project would be reviewed for its implications in that area, and the Moon base has some positive attributes as a secure observation and communication post. Activities on Earth can be seen, and it is not generally realized that more than 95% of geosynchronous orbit can be viewed from the near side of the Moon at all times. Communication time to the Earth is seconds while travel time is days. Finally, we point out that an eyewitness to hostile activity adds enormous credibility to sensor measurements, however sophisticated they may be.

We have discussed factors in the political-economic equations, and have neglected the exciting and important science to be done, because we want to emphasize the probability of a decision point in the early 90's. NASA must prepare for the decision through maintenance of a healthy lunar research and analysis program over the next ten years. The programmatic objectives must include preparation of a fiscally viable and technologically challenging strategy for establishment of an international research laboratory on the Moon. We believe this can be done within a modest but stable budget, designed to support a healthy continuity in research without creating a population explosion.

Project Apollo returned a wealth of scientific information, and it commonly is assumed that exploration of the Moon is complete. The lunar samples are rich sources of information for the Apollo landing sites but represent the rest of the Moon only in an average sense. Orbital remote sensing data from the "J" missions allow geochemical inferences for much of the low latitudes, but the mapping is nowhere near complete. Photographic coverage of the Moon lags behind that for Mars. For example, the lunar polar regions are popular candidates for a lunar base but very little is actually known about them.

Thus the critical element and the pacing item for the first phase of the lunar initiative is an unmanned scientific satellite collecting data in lunar polar orbit for at least six months. At JSC we have formulated two related mission concepts for an Advanced Lunar

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Mapping Satellite, based on the well analyzed Lunar Polar Orbiter mission proposal. One mission profile is a simple Shuttle launch to lunar orbit; the second profile adds demonstrations of certain capabilities of the STS and features a return of the entire spacecraft to Earth orbit upon completion of the lunar mission. Cost estimates for either scenario fall well below typical Mariner class planetary missions.

A new start for a lunar mission can be put in the NASA budget no earlier than FY85. The launch would occur by the end of this decade, and the first well analyzed data would be available in the early 90's, when our predicted decision point occurs. If we act now, we can be ready.

As our preaching has spread beyond the choir to the congregation, and even outside the church, we become ever more exposed to critical cross-examination by nonbelievers. The hardest, often raised question concerns economic return - not the long term benefits touted by advocates of space colonization but rather the near term payback for this next step in space. Unfortunately, the Moon could not be more desolate, more devoid of riches. On the other hand, we have two real advantages over our predecessors who have wrestled with this problem. As a scientific and engineering community, we know more about the Moon and also we can deal more realistically with the options in the lunar transportation system. Our guesses are more educated, and our confidence level can be higher.

From the economic point of view, the Moon's most significant attribute is its "proximity", in terms of gravitational potential, to Earth orbit. Any lunar product can make an immediate impact on the economic equation if it is needed in quantity by the STS and if it requires minimal processing. So far we identify two candidates. Simple dirt can be used as radiation shielding in a polar orbit space station or for any manned mission beyond low Earth orbit. Hundreds of tons of mass are required for such an application. The second, and more valuable, potential resource is lunar oxygen for fuel. Production of oxygen from rocks could double or triple the payload capacity of the Shuttle fleet and make a profit from the lunar operation. Other, more subtle, options surely will appear as we have the opportunity to learn more about the Moon and as we actually can pay people to think about the problem!

Why are we talking about a lunar base now? NASA, as part of its responsibility for input to space policy must determine the scope, the advantages, and the difficulties of the lunar option in anticipation of important decision processes in the early 90's. NASA can utilize a modest, long term program of lunar research and analysis to provide disparate activities in science and in engineering and in technology development with a common vision and a new excitement. The vision is important to us all; the time for it is now.

A GIANT FOOTHOLD FOR MANKIND Dr. George Mueller, Systems Development Corp., 2500 Colorado Ave., Santa Monica, CA 90406

If we decide to utilize the moon, several considerations come to mind. Military installations and operations on the moon are prohibited by the 1967 Space Treaty. Technical and scientific motivations impel us to establish research laboratories on the moon for further study of planetary evolution and, on the far side, establishment of radio telescope capability which would be shielded from background noise from the earth. This could be accomplished on an international basis, and the idea of a Lunar International Laboratory (LIL) was suggested and explored by the IAF in the early 1960s. The extraction of propellants from lunar material, including the possible finding of sub-surface water near the poles, could significantly enhance the feasibility of far-earth space operations and our eventual expeditions to our neighbor planets. Use of lunar resources has been suggested for fabrication of large constructions in space, such as Solar Power Satellites (SPS) in geosynchronous orbit. I suggest that we explore establishing solar receivers on the moon itself, from which the received power would be beamed directly for use on the earth. The geometry of such an arrangement naturally suggests that this should be a cooperative international effort. Further, advances in earth moving and tunneling technology over the last few decades suggests that much of the supporting operations for these sorts of activities might be located far beneath the lunar surface. While there may not yet be an economic justification for man to return to the moon, nevertheless it is a logical stepping stone in humanity's search for our destiny in growing from cradle earth into the universe. It seems almost certain that either we or the Russians will take that path.

FUTURE UNMANNED LUNAR SPACEFLIGHTS. Don E. Wilhelms, U.S. Geological Survey, Menlo Park, CA 94025

Much remains to be learned about the Moon despite the technological and scientific successes of the last two decades. Its mode and place of origin are not known. Its subsurface structure is very poorly known even in relatively well explored areas. Not even its topography has been satisfactorily mapped in most regions. The rate of the impact flux before 3.85 aeons is not well calibrated, so that such important points as the time of crustal solidification and the origin and lifetime of large solar-system projectiles are not agreed upon. The dates of volcanism after 3.2 aeons are uncertain. The ages of most of the rayed craters are uncertain within broad limits. The relation among composition, source depth, and extrusion site of mare basalt is hypothetical. The compositions of the farside maria are not known. Terra compositions are known only very crudely from a few spot samples extrapolated by low-resolution orbital measurements of a small percentage of the surface. The origins of crater central peaks, basin rings, and even basin topographic rims are elusive. Mars may have been better photographed than the Moon.

Some of the questions can probably be answered by continued experimental and field study on Earth and by continued examination of the 80 percent of the lunar samples which have not yet been thoroughly analyzed (Ryder, 1982). Answers to most of the remaining geologic questions, however, require resumption of lunar spaceflights. As was true before the Apollo landings, the first of this new series of flights should be unmanned. A future lunar base can be neither effectively sited nor productively planned without additional unmanned exploration. Global orbiters and targeted landers are both needed.

Near-polar orbiters could gather important data concerning (1) topography, especially in and near basins; (2) the gravity fields of the Moon and of basins; (3) mare compositions; (4) terra compositions, an even more serious gap; (5) the puzzling problem of magnetism; (6) the stratigraphy of poorly photographed regions, particularly the polar regions above 40° latitudes, a zone along longitude 100-120° W, and the east limb on both the near and far hemispheres. Knowledge of the Moon's third dimension could be greatly improved by this remote exploration.

Other problems require additional samples from the Moon itself. The attached table gives some tentative recommendations for landing sites of unmanned sample-return spacecraft which could provide important geologic data. Each probe is considered capable of returning a single sample of regolith randomly selected from within the designated area. Objectives fall into five main categories: (1) absolute ages needed to calibrate the stratigraphic column, (2) compositions and textures for deciding genetic problems such as the hypothetical terra volcanism, (3) crustal compositions at points of known stratigraphic context which can be extrapolated to larger areas, (4) mantle compositions inferable from samples of currently unsampled color- and age units of mare basalt, and (5) pre-mare volcanic basalts. Data from most of the selected targets can be extrapolated by means of currently available or future orbital sensing. Petrologists and geochemists might have a different list. An additional requirement, not specifically addressed here, is for new seismic data to determine crustal thickness and other poorly known properties of the interior.

UNMANNED SPACEFLIGHTS

Wilhelms, D. E.

Potential landing sites for unmanned lunar sampling missions.
Prepared with contributions by Paul D. Spudis.

Prior.	Stratigraphic unit	Landing area	Main objectives
1.	Nectaris basin	(a) Ejecta, near 35° S, 42° E (b) Plains near 22° S, 41° E	Absolute age; crust compos.
2.	Copernican mare	SE of Lichtenberg, 31° N, 67° W	Abs. age; compos.
3.	Terra plains (see also #11)	(a) Albategnius (b) Ptolemaeus	Nonmare volcanism or buried mare
4.	Terra domes	(a) Gruithuisen gamma or delta (b) Hansteen alpha	Nonmare volcanism?
5.	Far-side mare	(a) Floor of Tsiolkovskiy (b) Mare Ingenii	Composition of source
6.	Maunder Formation (Orientale melt)	South of Mare Orientale	Age of basin; crust. compos.
7.	Copernicus	Impact melt on floor	Age; deep crust?
8.	King	Impact melt on floor	Farside crust; age
9.	Ancient crust	Near 30° N, 160° E	Composition; age
10.	"Big Backside Basin" massifs	South of Korolev, 22° S, 160° W	Crust compos.; age
11.	Pre-Late Imbrian mare(?) basalt	(a) Center of Schickard (b) North of Balmer	Absolute age; composition
12.	Old (KREEPy?) mare	Mare Marginis, in Ibn Yunus	Ditto
13.	Eratosthenian mare	(a) SW Mare Imbrium (b) Surveyor 1 region	Age; calibrate color spectra
14.	Central Mare Seren.	Between Bessel and Dawes	Ditto
15.	Orientale ejecta lobes	Near 53° S, 79° W	Impact melt?; crust compos.
16.	Alpes Formation	SE of Vallis Alpes, 45° N, 5° E	Melt or debris? deep ejecta?

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ENHANCED PRODUCTION OF WATER FROM ILMENITE: AN EXPERIMENTAL TEST OF A CONCEPT FOR PRODUCING LUNAR OXYGEN. Richard J. Williams, SN, NASA/Johnson Space Center, Houston, TX 77058 and Oscar Mullins, C-23, LEMSCO, Houston, TX 77058.

Many studies (e.g., 1,2) have noted that large amounts of propellant are required for orbital transfers in expanded space transportation systems. If a source of propellant were available in space, the efficiencies of such transportation systems could be improved as a result of savings in energy from reduced Earth to orbit transport. Other studies (e.g., 3,4) have proposed that the rocks and minerals found on the Moon might be a source of oxygen for use as the oxidizer in H_2/O_2 rockets and a number of more or less complex schemes for obtaining oxygen have been proposed. The most simple of these proposals involves the reaction of hydrogen with iron oxide bearing minerals to produce water from which hydrogen and oxygen are subsequently recovered.

Of the several candidate lunar minerals, ilmenite is an ideal choice: it is locally quite abundant (up to 5% (modal) in some Apollo 17 soils), it can be separated from that soil (5), and it is relatively rich (58% by weight) in the reducible FeO component. The basic production reaction would be: $H_2 + FeTiO_3 = Fe + TiO_2 + H_2O$. Unfortunately, at moderate temperatures (500^0 to 800^{0}C), the per pass conversion of H_2 to H_2O is less than 5%. The conversion can be increased by running the reaction at higher temperatures but the degradation of reactor material, hydrogen loss by diffusion from the reactor, and sintering of the solid reactants and products became major problems above 1000^{0}C.

Williams (5) suggested that the per pass yield could be improved if the H_2O pressure were buffered by the water liquid-vapor equilibria. If such buffering is possible, the water vapor pressure can be maintained below the equilibrium water vapor of the reaction, $H_2 + FeTiO_3 = Fe + TiO_2 + H_2O$. Consequently, water will be transferred from the vapor to the liquid phase, the reaction will be forced to the right, and per pass conversion will increase.

The computed "equilibrium" hydrogen pressures for several reaction and cold trap temperatures are given in Table 1.

Table 1. Equilibrium Hydrogen Pressures (psi)

T(^{0}C) (cold trap)	10	20	30
(Reaction)			
600	5.7	10.9	19.7
700	4.1	7.8	14.1
800	3.1	6.0	10.9

The equilibrium hydrogen pressure is independent of the initial hydrogen pressure. Thus, if the initial hydrogen pressure were 20 psi, the cold trap 10^{0}C, and the reaction 800^{0}C, the per pass conversion would be 84.5%. This should be compared with 5.7% conversion without a cold trap.

We have constructed a breadboard apparatus and tested the above principle. The apparatus consists of a stainless steel reaction vessel into which dry hydrogen can be introduced. The reaction vessel can be isolated by valves and the pressure monitored by a solid state pressure transducer. One outlet from the vessel connects to a small cold trap. The experimental procedure is:

1. The vessel is filled with powdered ilmenite, evacuated and flushed with argon several times, and then heated to the desired process temperature.
2. Hydrogen is then introduced; the vessel is isolated and the pressure monitored to check for leaks.
3. Finally, the valve to the cold trap is opened and pressure recorded as a function of time.

When a hydrogen/ilmenite assemblage (T = 720°C; hydrogen pressure 20 psi) was connected to a cold trap, pressures drop smoothly from 18 psi to 9.2 psi after initial fluctuations. The pressure as a function of time (minutes) is given by the equation: $P = 9 + (9/t)$. We obtained production rates of 0.003 moles of H_2O per hour from experiments at 720°C in a non-optimized system. Currently, we are modifying the system before obtaining a full set of data; we plan to construct a full prototype this year.

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